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This report summarizes the research and development that has been carried out at Lawrence Berkeley Laboratory to develop a novel kind of high current metal ion source for metallurgical surface modification application. In ion implantation, an energetic ion beam is injected into a solid surface with the result that the surface composition is changed. For the case when the surface is a metal, the tribological properties of the new metallurgical surface can be significantly improved over the unimplanted surface. Previously, however, very intense metal ion beams have not been available, and this has been an impedance to the development of the field. With the MEVVA (Metal Vapor Vacuum Arc) ion source, metal ion beam currents of very high intensity have become available. In this report we outline the progress made under the funded program in the four areas addressed: development of the MEVVA ion source for ion implantation application; research on the ion beam characteristics and behavior; development of our ion implantation facility; metallurgical ion implantation research that we have carried out.

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HIGH CURRENT METAL ION IMPLANTATION

Final Report

Ian G. Brown

April, 1990

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FOREWORD

The surface modification of metals by ion implantation is a field of research with important potential applications to a wide range of technological areas. The implanted material can be harder and smoother; it can have wear characteristics that are much superior to the unimplanted surface; resistance to fatigue can be greatly improved; resistance to corrosion can be increased by orders of magnitude; the electrical properties can be changed. Although semiconductor ion implantation is a well-established and accepted technology, metallurgical ion implantation is still an emerging technology that is starting to make the transition from research laboratory to industrial plant.

It has until recently been the case that metal ion beams of high intensity have not been conveniently available to the experimenter, and this has been an impedance to the growth of the field. With the development of the MEVVA (Metal Vapor Vacuum Arc) ion source, however, metal ion beams of extremely high intensity have become available, providing a means for carrying out a wide range of metal ion implantation experiments and applications.

The research program summarized here was carried out to investigate the application of a new kind of high current metal ion source, previously invented and developed at Lawrence Berkeley Laboratory for heavy ion synchrotron injection, to the field of metallurgical ion implantation. Limits of an earlier ion source embodiment were determined and a new source version was designed specifically for high current, high dose metal ion implantation. At the same time some fundamental ion implantation research experiments were carried out.

CONTENTS

A. STATEMENT OF THE PROBLEM STUDIED

(i) Background

Ion implantation is a process in which an energetic ion beam is injected into the surface of a solid material with the result that the surface composition is changed and thereby also the properties of the material surface [1-9]. The implanted material can have surface characteristics that are much superior to the unimplanted surface. Metallurgical applications include: reduction of friction and increase in lifetime of metal bearing surfaces; hardening of cutting and clamping edges of industrial tooling and machinery components; stress modification; enhancement of corrosion resistance; improved fatigue resistance; modification of electrical conductivity.

In metallurgical ion implantation, a relatively small fraction of added atoms is used to create a new surface alloy with enhanced surface metallurgical properties under a variety of conditions. However, it has to-date been the case that beams of metal ion species have not been available in significant intensity. This has been an impedance to the development of the field.

The MEVVA (Metal Vapor Vacuum Arc) ion source is a new kind of source that has been invented and developed at LBL for use in the heavy ion nuclear physics research program. With the development of the MEVVA ion source, metal ion beam currents of unprecedented intensity have become available for a wide range of metal species.

The goal of this research program was to develop the MEVVA ion source to demonstrate its utility for large scale metallurgical surface modification, and to simultaneously carry out basic research in high dose metallurgical ion implantation.

(ii) The MEVVA Ion Source

In the MEVVA ion source a metal vapor vacuum arc is used as the means for producing the plasma from which the ion beam is extracted. This kind of discharge is a prolific and efficient source of dense metal plasma formed from the cathode material; a carrier gas is not required, and a metal ion plasma is created in the vacuum ambient. The vacuum arc discharge has been studied experimentally for many decades; an historical survey of the field, pre-1960s, has been given by Cobine [10], and more recently a review of the entire field of metal vapor arc discharges has been given by Lafferty [11]. A review of cathode spot behavior has been given by Lyubimov and Rakhovskii [12]. A cylindrically-symmetric configuration is used in this embodiment; this arc geometry has been studied by Gilmour and Lockwood [13], and the LBL design has drawn extensively upon this work. The plasma plumes away from the cathode toward a set of multi-aperture extractor grids, where the ion beam is formed from the plasma. A number of different sources with different characteristics and performance parameters have been made for injection into the LBL heavy ion synchrotron, and the family of MEVVA II, MicroMEVVA and MEVVA IV is shown in Figure 1. The MEVVA ion sources have been described in detail in several publications [14-17].

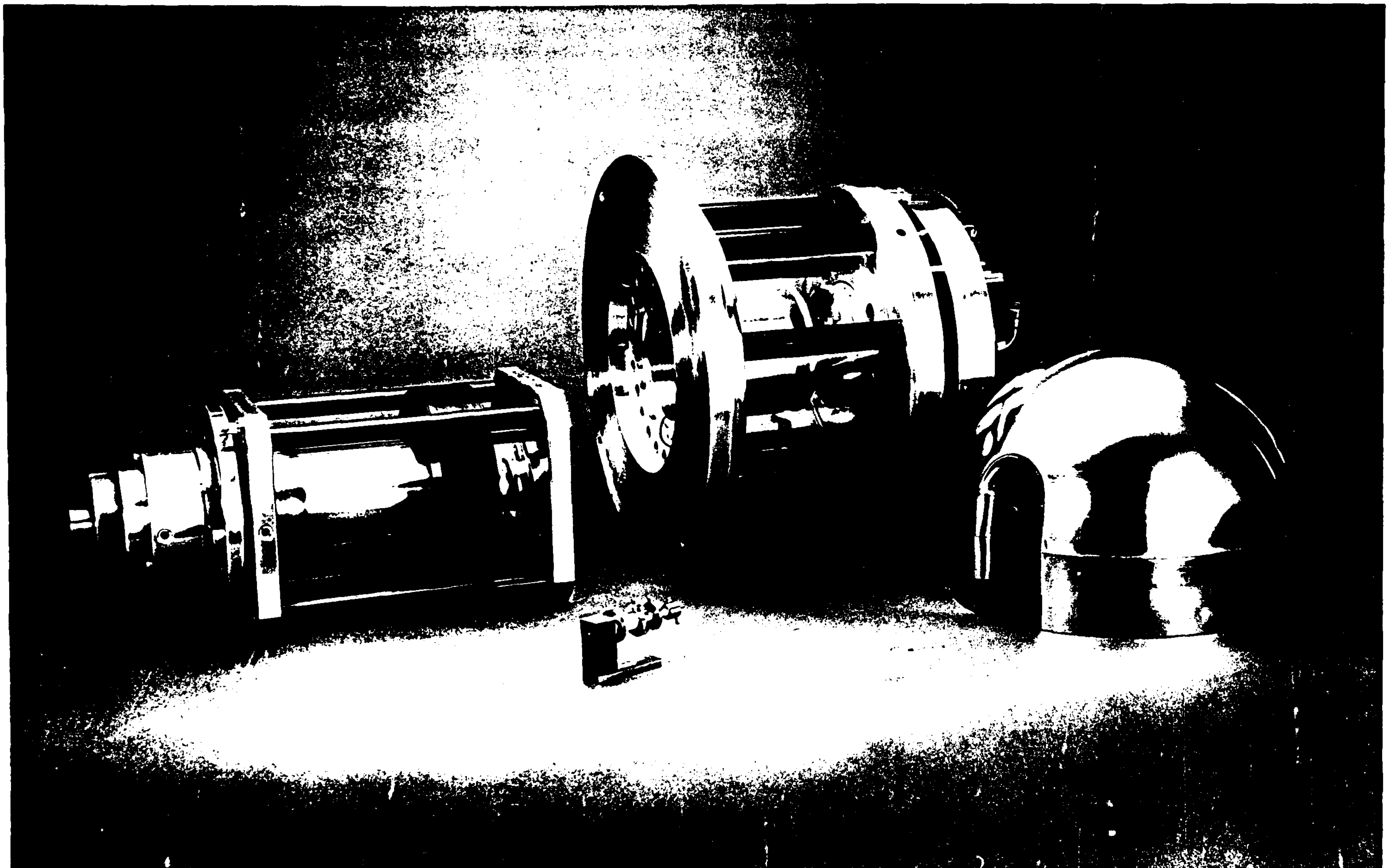

Fig. 1 The three ion sources MEVVA II (left), MicroMEVVA (foreground), and MEVVA IV (right) developed for accelerator injection application.

(iii) Importance of the MEVVA Ion Source to Large Scale Metallurgical Ion Implantation.

The distinctive feature of the MEVVA ion source that is important to this application is the very high current of metal ions that can be produced. Measurements have shown that the plasma ion current that is available for extraction from the MEVVA source can be as high as 5% of the current employed to drive the vacuum arc; we have measured a plasma ion current, at the location of the extractor and available for extraction, as high as 20 Amps with the present embodiments of the source concept [18]. This is greater than that presently available in conventional implanters by many orders of magnitude, and the potential impact on large scale ion implantation is great. Prior embodiments of the MEVVA source concept made at LBL have been made specifically for synchrotron particle injection, and have thus been of low duty cycle. However this is not an inherent feature of the source and with the appropriate upgrading of cooling and power supplies, operation at a duty cycle of several tens of percent, or at dc, is possible.

Since the method by which the plasma is created is a vacuum arc discharge, no support gas is required. This is of major significance to the application of MEVVA implantation to very large size workpieces and/or high throughput lines. With conventional gaseous ion sources the need for large pumping facilities to maintain adequate vacuum is a concern which can become a limiting factor as the scale is increased. With the MEVVA source, pumping requirements are minimal.

It is an inherent feature of this kind of ion source that the beam composition is particularly pure, reflecting precisely the composition of the solid cathode material. No magnetic analysis of the beam is required, thus vastly simplifying the implanter design, increasing the efficiency of beam transport onto target, and greatly reducing the size, complexity and cost.

As an example of the kinds of implants that are attainable using the MEVVA technology, consider a source with an arc current of 200 A (as is presently used), a duty cycle of 10% (a factor of ten greater than presently used), and with the appropriately upgraded power supplies. This source could deliver a beam with a current of 10 Amperes peak (during the pulse-on time) and 1 Ampere mean current, at a mean beam power of 50 kW. If, for example, the cathode material was titanium, for which the mean charge state has been measured to be $\bar{Q} = 2.14$, a 100 keV ion beam would be produced at an extraction voltage of 47 kV. This beam would be capable of implanting to a dose of 5×10^{16} cm^{-2} at a rate of 60 cm^2/sec. The time-averaged beam power of about 50 kW might be too high, and one might choose to limit the implantation rate for reasons of power supply economy and/or target cooling. The significant point is, however, that for the first time, the implanter performance would not be limited by the ion source, but rather by other considerations. This is a revolutionary development.

Alternatively, a super-high-flux metal ion implanter might consist of many individual units, say 10 - 100, each of hand-size and delivering a peak current of several hundred milliamperes, positioned around the walls of an implantation chamber so as provide optimal coverage for the implant target. The time-averaged, spatially-integrated beam current might still be 1 Ampere, at an extraction voltage of 50 kV, as in the example above. This approach would be very flexible, and would be a goal attainable with only modest scale-up indeed from our present sources.

These examples illustrate a near term goal of a long range program. The ultimate limitation to the spatially-integrated beam power that would be sensible to entertain would be set by considerations other than the ion source (or source cluster), for example the input electrical power requirements or cooling requirements of the implanter facility, or more likely the maximum permissible surface temperature of the target. The target surface temperature limit may be high, however, as beam-induced annealing of the implanted zone could be a serendipitous bonus.

(iv) The Research Program

The technical objectives of this program were to develop the MEVVA ion source technology and to demonstrate its utility for carrying out large scale metallurgical surface modification by high dose rate metal ion implantation. The program thus involves two parallel components: ion source development and ion implantation research.

Progress made under the funded program can be divided into the following four areas: (i) ion source development, (ii) research on ion beam characteristics and behavior, (iii) development of our ion implantation facility, and (iv) ion implantation research. These four areas are now summarized.

B. SUMMARY OF RESULTS

(i) Ion Source Development

A major achievement of this program was the design, fabrication and commissioning of the MEVVA V ion source. This is a high current, broad beam source version whose purpose is specifically for ion implantation. This was thus the first MEVVA source to be made for implantation as opposed to particle accelerator injection. Beyond the MEVVA V, under the funding period of this contract we also designed and fabricated the first test version of MEVVA VI - the first dc MEVVA ion source.

Firstly we made a "plasma expander", to capture a high fraction of the vacuum arc metal plasma created at the cathode and to expand the captured plasma to a large diameter. This device has the form of a conical permanent magnet multipole structure. Measurements were made of the radial density profile of the expanded plasma. We found that the device efficiently trapped plasma that previously was lost, and provided a fairly uniform density profile at the location that the extractor would occupy. We then fabricated a large area ion beam extractor of simple design. The extractor grid area was approximately 80 cm^2, compared to the previous extractor area of approximately 3 cm^2. Despite a lack of sophistication of this preliminary test configuration, we were able to extract short pulse metal ion beams of current up to nearly 10 Amperes - this is a very high metal ion beam current.

Having met with good success with the test version of the upgraded ion source, we then designed, fabricated and tested a properly-engineered new ion source - the MEVVA V. Final testing and commissioning of our new ion source, MEVVA V - a multiple cathode, broad beam, high current, source embodiment - has been completed. In this source 18 separate cathodes are mounted in a single cathode assembly, allowing the operational cathode to be changed simply by rotating a knob so as to position the desired cathode in line with the anode and extractor of the device. The source can produce beams of up to 18 separate metallic ion species with a single 'loading' of the cathode assembly. Removing the cathode assembly, changing the individual cathodes, and re-mounting the assembly can be done quite quickly also. Many different cathode materials can be compared in a relatively short experimental run and with confidence in maintaining the same experimental conditions. The extractor diameter is 10 cm and the individual holes in the grids are of diameter 4.7 mm. A photograph of the MEVVA V source partially disassembled to show the multiple cathode feature is shown in Figure 2.

The source has performed well both as an advanced metal ion source and also as the kernel of our ion implantation facility. Beam current is typically of order 1 Ampere peak delivered onto target, corresponding to a time-averaged current of up to 10 - 20 mA or more. Beam divergence is typically about 3^o. Operationally, the arc current is varied so as to maximize the beam current measured into the acceptance of a downstream Faraday cup, which occurs when the plasma density is best matched to the extractor parameters. Maximum voltage at which beam has been extracted is 110 kV. Several papers describing the MEVVA V and its performance characteristics were presented at the International Conference on Ion Sources held in Berkeley in July, 1989 [19-21].

Cathode lifetime is limited by erosion of the surface by the arc, and is up to around one million shots per cathode depending on the arc current and pulse length; thereafter triggering becomes erratic and difficult. There is normally no significant deterioration in either the trigger or the trigger insulator. Since in the MEVVA V there are 18 cathodes in a single multiple cathode assembly, the source can be operated steadily for many days before it is necessary to vent the source to atmospheric to replace the cathodes. Soft materials like Li, Sn and Pb tend to have a shorter lifetime due to plating over of the cathode/trigger insulator, but this depends on the arc current.

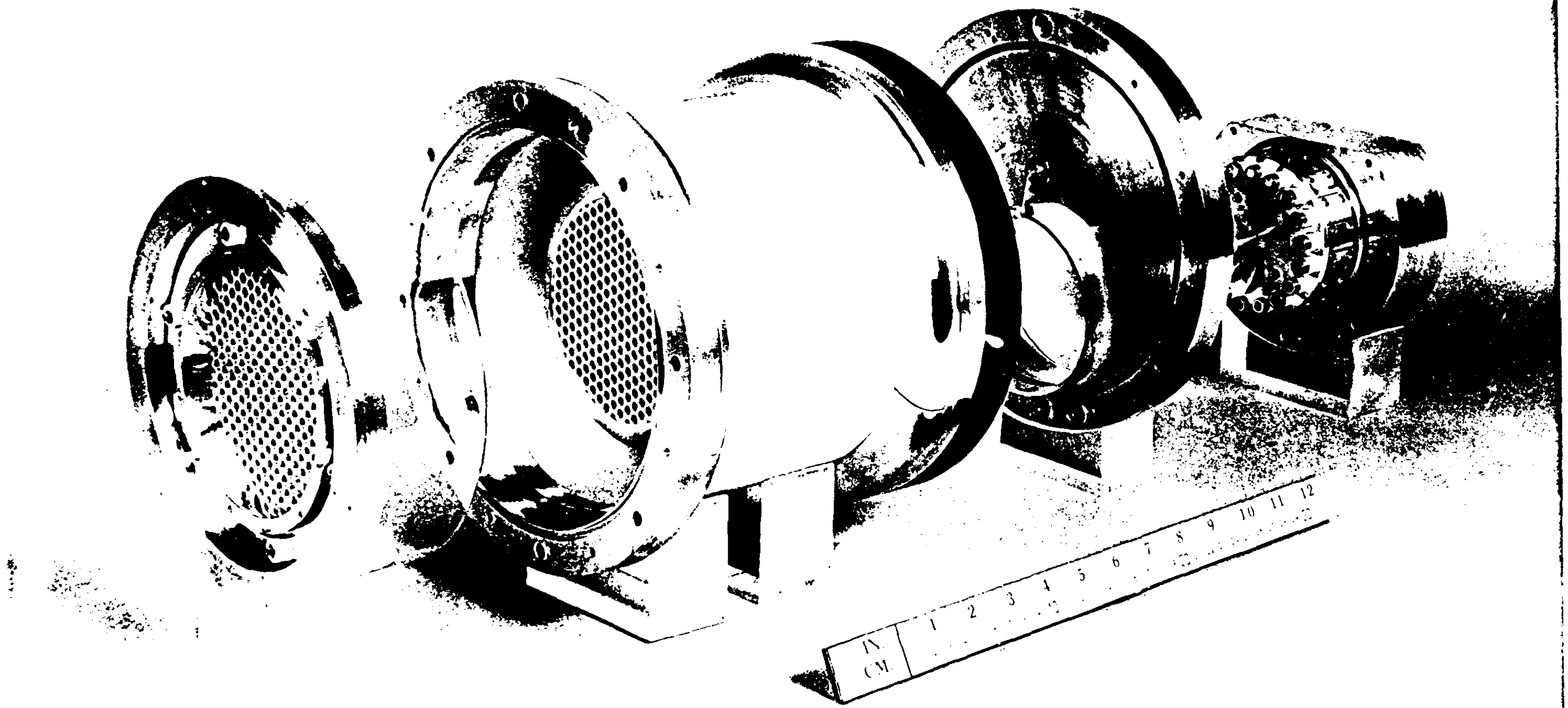

Fig. 2 The MEVVA V ion source, partially disassembled to show the multiple cathode feature (holds 18 separate cathodes) and the large beam formation electrodes.

To extend the source operating lifetime further and to increase the beam current yet higher, it is necessary to utilize a larger cathode and to provide more cooling. We thus carried out a small program of investigation of an advancing cathode concept. in which the cathode moved forward progressively as the front surface was eroded away by the vacuum arc, and maximum cathode cooling was achieved by direct water flow around the cathode rod itself. The results were encouraging, but we decided that the best approach was not with a small diameter cathode, even though advancing and operating at high duty cycle, but rather with a large diameter, "hockey puck" cathode which could be run truly dc.

Thus the decision was made to go ahead with a dc source concept as a means for making the next major step forward in the long term goal of ultra-high beam current metal ion implantation. A new metal vapor vacuum arc plasma gun with true dc capability (ie, many hours on-time) was designed and fabricated in the funding period of this project.

(ii) Ion Beam Characterization

We studied the charge state distribution of the ion beam produced from a wide range of different cathode materials. The charge state distribution was measured using a time-of-flight (TOF) diagnostic; this system has been described in reference [22]. Oscillograms of the time-of-flight charge state spectra for titanium and tantalum, as examples of typical data, are shown in Figure 3; the titanium spectrum is peaked at Q = 2 and the tantalum at Q = 3. The array of cathodes that we have accumulated contains 48 different elements, nearly all of the solid metallic elements of the Periodic Table - Li, C, Mg, Al, Si, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ge, Sr, Y, Zr, Nb, Mo, Pd, Ag, Cd, In, Sn, Ba, La, Ce, Pr, Nd, Sm, Gd, Dy, Ho, Er, Yb, Hf, Ta, W, Ir, Pt, Au, Pb, Bi, Th and U [23,24]. We've also investigated the spectra produced by a range of compound and alloy cathode materials, including for example TiC, SiC, UC, PbS, brass, and stainless steel [25]. The compound cathodes produce a beam containing ions of the molecular constituents, and it is interesting to note that beams containing non-metallic elements, like B and S, can be made by using conducting compound electrodes of which the non-metal is a constituent. The ions produced are in general multiply stripped, with charge states as high as 5 or 6 for some elements and with mean charge state from 1 up to about 3. This means that the mean ion beam energy is greater than the extractor voltage by this same factor, with the beam containing discrete energy components at multiples of the extraction voltage. These data have been tabulated for all of the elements and compounds investigated [23-25]. These data form a valuable data base that is important for implantation applications, as well as being a unique and important contribution to the field of vacuum arc physics. These results will be presented at an upcoming conference, and we will submit a detailed paper for publication.

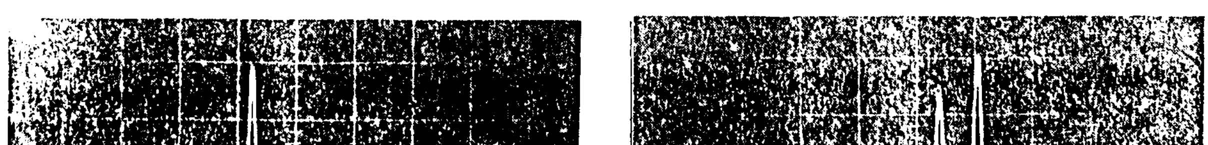

Fig. 3 (a). Time-of-flight titanium charge state spectrum. The peaks correspond to Q = 1, 2 (maximum) and 3, right to left. (b). Time-of-flight tantalum charge state spectrum. The peaks correspond to Q = 1, 2, 3 (maximum), 4 and 5, right to left.

A parametric study of the beam noise (fractional current fluctuation level) was completed. The noise minimizes at an arc current corresponding to the "perveance match condition". Ie, when the arc current creates a plasma of density that is optimally matched to the beam formation electrodes, then not only is the beam current maximized and the divergence minimized, but also the noise is minimized. These results thus provide a guide to optimal source operation. This work has been written up and will be submitted for publication in Nucl. Instrum. and Methods, Part A.

A detailed experimental characterization of the MEVVA V ion source was carried out. The ion beam current was measured as a function of source parameters such as arc current, extraction voltage, cathode species, and extractor grid spacing. Optimum operating conditions of the MEVVA ion source were determined. This series of measurements completes the MEVVA V ion source studies. This work is presently being prepared for publication.

(iii) Ion Implantation Facility Development

A schematic of the overall experimental configuration is shown in Figure 4. The implantation facility now uses the MEVVA V ion source. The source is operated in a pulsed mode with a pulse length of 0.25 msec and a repetition rate of up to about 100 pps. The implantation is done in a broad-beam mode, without magnetic analysis of charge-to-mass beam components. The ion trajectories are line of sight from ion source to target. At the high beam current density present here, this is a necessity: the high ion beam charge density demands a very high degree of space charge neutralization of the beam, and any attempt at magnetic analysis would cause a major perturbation to the neutralizing electrons and destroy or disturb the neutralization, with consequent space charge blow-up and loss of beam. This is an issue of some importance; magnetic (or other) charge-to-mass analysis of high current density ion beams is a concern for a number of different applications, and is the subject of some research worldwide. Unlike many other kinds of ion sources, the MEVVA source produces a beam that is particularly pure, containing a very high fraction of just the wanted ion species. This is because the plasma is formed solely from the cathode material, where the cathode spots of the vacuum arc are active, and there is no carrier gas. Thus the beam composition is essentially just the wanted metal species and for metallurgical ion implantation applications a broad-beam, line-of-sight implantation poses no problems.

The target to be implanted is introduced into the vessel through an air lock. This permits minimal gas into the vessel and the turn-around time between target changes can be quite short, a matter of minutes. The target is suspended from a vertically moving shaft. The source-to-target distance (ion source extractor grids to target holder) is 65 cm. We have fabricated several different target holders for different applications, including a motor-driven, continuously rotating holder for cylindrical targets. The target holder is water cooled and the water temperature rise is monitored with thermistors, thus providing a calorimetric measurement of beam power dissipated in the target.

A magnetically-suppressed Faraday cup with a 5 cm diameter entrance aperture can be inserted into the beam immediately in front of the target, providing a good monitor of the ion beam current density at (or close to) the target location. This provides a means for adjusting the beam current prior to commencing actual implantation, and the number of beam pulses required for a given implantation can be calculated. We have made numerous comparisons between the beam current as indicated by the Faraday cup and calorimetrically, and also compared this to the actual implanted dose as determined by Rutherford Backscattering Spectrometry (RBS), and there is good agreement between these methods. In general we can obtain a required dose to within a few tens of percent. An example of the implanter beam current performance for the case of a titanium beam is shown in Figure 5. Here the ion beam current density (during the beam pulse) delivered onto target, as measured by the Faraday cup near the target location, is plotted as a function of extraction voltage for a range of different arc currents. The peak ion current density is as high as 20 mA/cm^2.

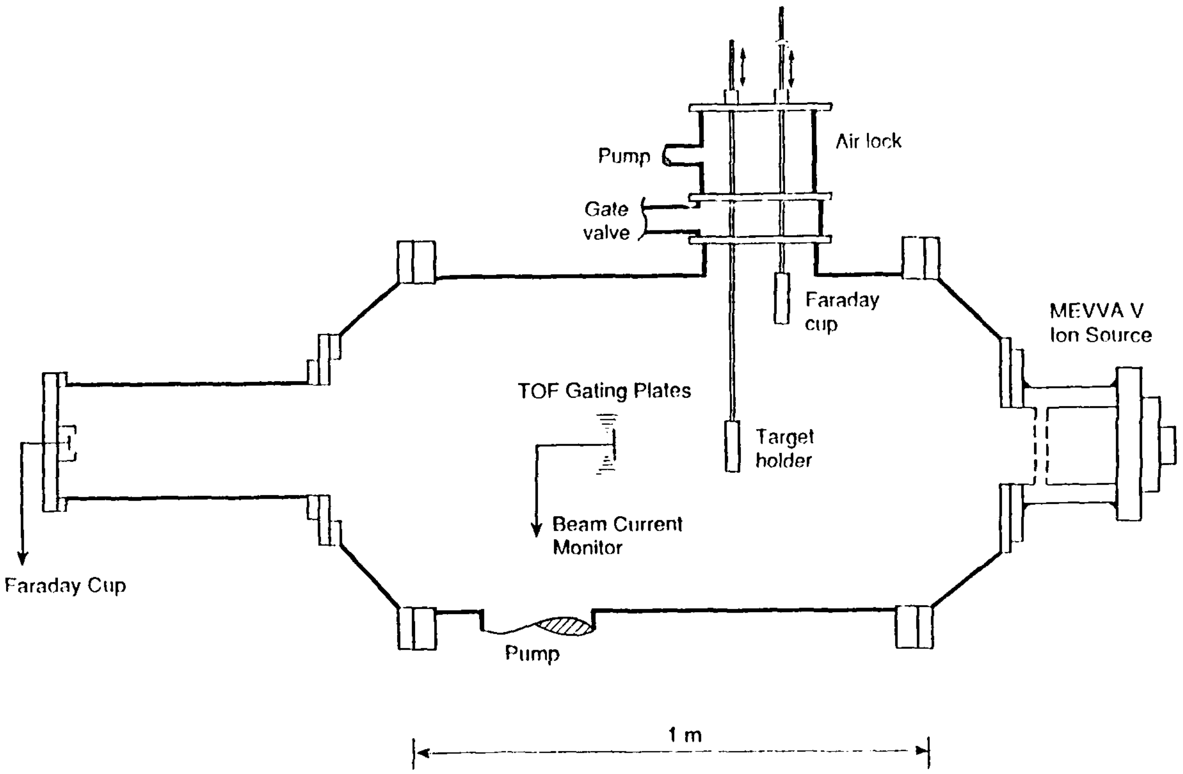

Fig. 4 Schematic of the experimental test stand and ion implantation facility.

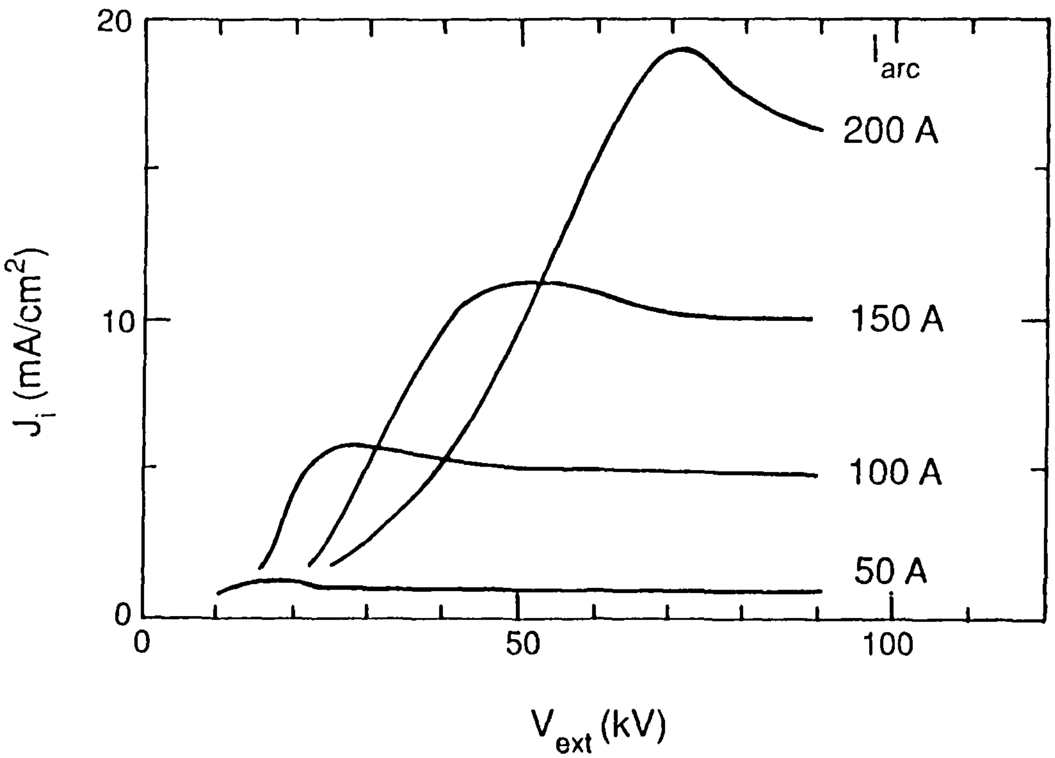

Fig. 5 Measured ion beam current density at the target as a function of extraction voltage for several arc currents. Titanium beam.

The ion beam charge state distribution can be measured as described above and in detail in ref [22]. The size of the gating plates array is such that one can continue to monitor the ion spectrum while an implantation is in progress, for all but quite large targets. The source might typically be pulsed at a rate of a several tens of pulses per second. For our standard pulse length of 250 μsec, a repetition rate of 40 pps corresponds to a duty cycle of 1%, and the mean beam current is then 1% of the peak (pulse) beam current. The vacuum pressure during implantation is typically in the low-to-mid 10^{-6} Torr range.

(iv) Ion Implantation Research

The new MEVVA V ion source is now routinely used for all our ion implantation work. It performs very well and has met all expectations. Using this source as our implanter as described above we have carried out a number of research efforts collaboratively with other workers. These programs are summarized below.

- Ti, Mn, Y, Zr, Ba, La, Ce, Gd, Hf, W, Th into alloys for high temperature oxidation inhibition [26,27]

The addition of minor amounts of reactive elements is known to have a beneficial effect on the high temperature oxidation of Cr_2O_3- and Al_2O_3-forming alloys above 900°C. The oxidation rate can be reduced by an order of magnitude or more, and the oxidation scale transport mechanism can be changed from predominantly outward metal transport to predominantly inward oxygen transport. The resulting scale that forms has an increased resistance to spallation, which is often related to a stronger adhesion. We have investigated the effect of ion implantation into an Fe-18Cr-5Al alloy and into a Ni-25Cr alloy as a means of inhibiting high temperature oxidation of the materia'. The implantations were carried out at a mean ion energy of approximately 100 keV and a dose of approximately 5×10^{16} ions/cm^2. The implanted species we have investigated include Ti, Mn, Y, Zr, Ba, La, Ce, Gd, Hf, W and Th. The results of our work to-date, for the FeCrAl substrate material, are summarized in Figure 6. Here the mass change of a small, implanted metal coupon is shown as a function of time as the sample is baked in oxygen at 1100°C in 2 hour cycles. It can be seen that some of the materials form an oxide layer that flakes off in a short time, while other implantations provide a protective oxide layer; the beneficial elements are Ce, La, Gd, Zr, Y and Hf. We are indebted to Dr. Peggy Hou, LBL, for collaboration in this work; these results will be reported in detail in the literature soon.

- Ti and TiC into steel for tribological improvement [28]

An important part of our metallurgical ion implantation program is directed toward the surface modification of hard steel for improving properties such as wear, friction and hardness. We are grateful to Dr. Bruce Sartwell and colleagues at NRL for collaboration in this work. We are investigating the tribological merit of implanting high doses of Ti and Ti + C. The implantation is done at a mean beam energy of about 120 keV, and the titanium concentration is as high as 40 atomic percent. A novel feature that we are pursuing is the viability of doing simultaneous implantation of Ti and C using the compositionally mixed beam produced by the MEVVA ion source when operating with a TiC cathode [25]. Preliminary results indicate that good friction and wear characteristics are indeed achieved, comparable in degree to the improvement obtained by Ti and Ti + C implantations using more conventional implantation techniques.

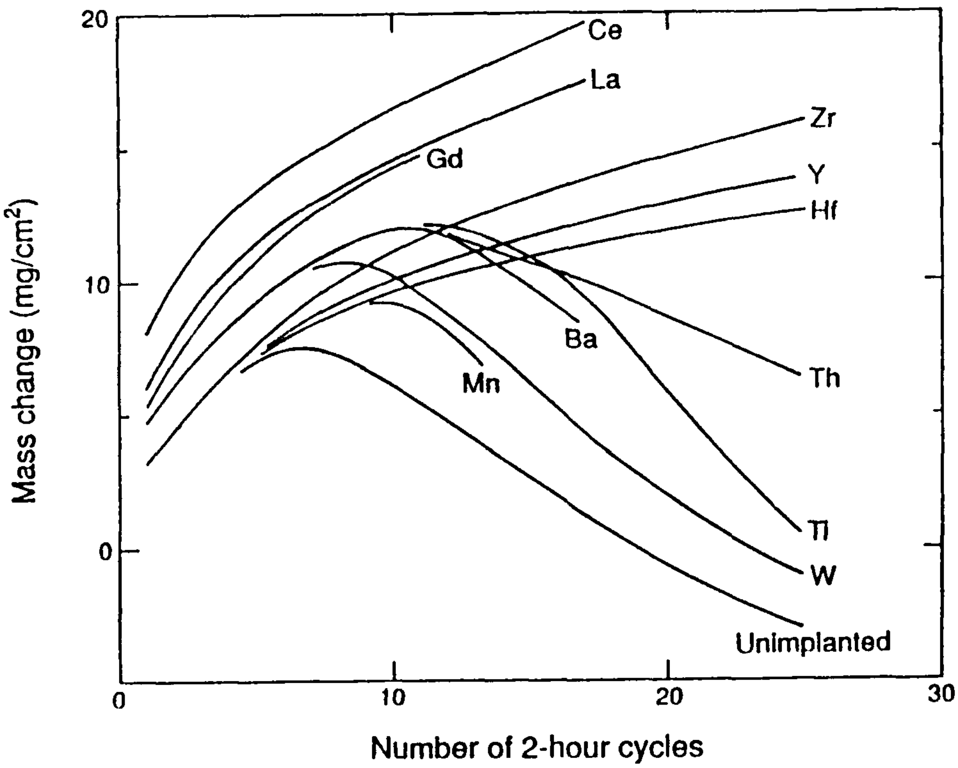

Fig. 6 Change in weight due to cyclic high temperature oxidation as a function of time, for various metal ion implantations into FeCrAl.

- Fundamental study of implantation depth profiles

A study of the implantation depth profiles of a range of metal ion species (Ti, Cr, Y, Zr, Nb, Mo, Pd, Ba, Dy, Ta, W, Ir, Pt, U) in a carbon substrate is being carried out collaboratively with Dr. Geoff Dearnaley of the UKAEA, Harwell, England. This fundamental investigation will clarify the effect of the broad ion charge state distribution (and hence energy spectrum) of the MEVVA-produced ion beam and will help in the planning and interpretation of surface modification work.

- Implantation of helicopter components

An interaction has been formed with the Ion Implantation Project of the Corpus Christi Army Depot, through Mr. Al Gonzales. The goal is to implant and field test a variety of helicopter parts as a means of demonstration of the value of metal ion implantation with the MEVVA technology to the in-the-field performance of machinery parts. One run involved the implantation of Mo into Al coupons for enhanced corrosion resistance; the corrosion testing is presently in progress. We are now fabricating a target manipulator for use in the implantation of Pd into steel bushings that are used in helicopter engines.

C. PUBLICATIONS

Papers published in refereed journals:

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"Performance of a High Current Metal Vapor Vacuum Arc Ion Source"
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LBL-27302
Submitted for publication in Rev. Sci. Instrum.

"Quantitation and Diffusion Characteristics of Uranium and Thoriumin Silicon"
A.J. Filo, F.A. Stevie, P.M. Kahora, V.C. Kannan, R. Singh and I.G. Brown
Submitted for publication in J. Vac. Sci. Tech.

"Formation of Iridium Silicide Layer by High Dose Iridium Ion Implantation into Silicon"
K.M. Yu, B. Katz, I.C. Wu and I.G. Brown
LBL-27554
Submitted for publication in J. Materials Research

"Metal Vapor Vacuum Arc as a Primary Ion Source for Secondary-Ion Mass Spectrometry"
B.H. Wang, I.J. Amster, I.G. Brown and F.W. McLafferty
Submitted for publication in Int. J. Mass Spectrom. Ion Processes

The following papers were presented at scientific conferences, and are to be or have been published in the Proceedings (as noted) after having been refereed by the standard peer review process:

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"Thin Film Synthesis using Miniature Pulsed Metal Vapor Vacuum Arc Plasma Guns"
X. Godechot, M.B. Salmeron, D.F. Ogletree, J.E. Galvin, R.A. MacGill, K.M. Yu and I.G. Brown
Materials Research Society Spring Meeting San Francisco, CA, April 16-21, 1990.

The following papers have been submitted for presentation at scientific conferences, and will be published in the Proceedings after having been refereed by the standard peer review process:

"Broad Beam, High Current, Metal Ion Implantation Facility"
I.G. Brown, M.R. Dickinson, J.E. Galvin, X. Godechot and R.A. MacGill
8th International Conference on Ion Implantation Technology,
Guildford, U.K., July 30 - August 1, 1990

"Metal Vapor Vacuum Arc Ion Implantation for Seeding of Electroless Cu Plating"
X.Y. Qian, M.H. Kiang, N.W. Cheung, M.A. Lieberman, I.G. Brown, X. Godechot and K.M. Yu
8th International Conference on Ion Implantation Technology,
Guildford, U.K., July 30 - August 1, 1990

"Morphology of Uranium Precipitates in Silicon"
V.C. Kannan, A.J. Filo and I.G. Brown
12th International Congress for Electron Microscopy
Seattle, WA, August 13-18, 1990

"Study of the Effect of Reactive Element Addition by Implanting Metal Ions in a Preformed Oxide Layer"
P.Y. Hou, I.G. Brown and J. Stringer
7th International Conference on Ion Beam Modification of Materials
Knoxville, TN, September 9-14, 1990

"Vacuum Arc Ion Charge State Distributions"
I.G. Brown and X. Godechot
14th International Symposium on Discharges and Electrical Insulation in Vacuum
Santa Fe, NM, September 16-20, 1990

"Metal Vapor Vacuum Arc Ion Sources"
I.G. Brown, M.R. Dickinson, J.E. Galvin, X. Godechot and R.A. MacGill
14th International Symposium on Discharges and Electrical Insulation in Vacuum
Santa Fe, NM, September 16-20, 1990

"Some Novel Surface Modification Applications of the MEVVA High Current Metal Ion Implantation Facility"
I.G. Brown, M.R. Dickinson, J.E. Galvin, X. Godechot and R.A. MacGill
Fourth International Conference on Surface Modification Technologies,
Paris, France, November 6-9, 1990.

The following papers were presented at conferences and and have been published in abstract form only:

"High Current Metal Ion Source for Ion Implantation"
I.G. Brown
Workshop on Research and Technical Transfer of Ion Implantation Technology for Speciality Metals
Knoxville, TN, October 26-27, 1989.

"Photoluminescence of the Actinide Uranium Implanted into Binary and Ternary III-V Semiconductors"
G.S. Pomrenke, M.B. Scott, R.L. Hengehold, Y.K. Yeo and I.G. Brown
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"Low Energy Metal Ion Beam Source"
X. Godechot and I.G. Brown
17th IEEE International Conference on Plasma Science
Oakland, CA, 21-23 May, 1990

Book: "The Physics and Technology of Ion Sources"
Ian G. Brown, editor (Wiley, NY, 1989).

D. PARTICIPATING PERSONNEL

Participants in this research program were:

Ian Brown, (PI),	senior physicist
James Galvin,	senior technical associate
Robert MacGill,	senior technical associate
Michael Dickinson,	technical associate

Additional technical support was provided as necessary by the various LBL support groups.

There were no postdoctoral researchers, graduate students, nor visiting researchers supported under this program. However, various guest scientists from a number of different laboratories and universities in the United States and overseas visited the laboratory and participated in various aspects of the research program for various lengths of times at their own expense (ie, costs paid by their own institution).

The following scientists visited my laboratory to participate in collaborative research as indicated:

(i) Dr. Frank Paoloni, University of Wollongong, Australia, for a 3- month stay as a participating guest, to participate in the MEVVA r&d program.

(ii) Dr. Peter Evans, Australian Nuclear Science and Technology Organization (ANSTO), for a 1-month stay, to participate in the development of metallurgical ion implantation applications of the MEVVA technology.

(iii) Prof. Jak Kelly, University of New South Wales, Australia, for a 1-month stay, to participate in the application of the MEVVA ion source for a possible new method of charge-to-mass separation.

(iv) Dr. Peter Spaedtke, Gesellschaft fur Schwerionenforschung (GSI), Darmstadt, W. Germany, for a 2-week stay, to participate in experiments on the beam noise characteristics of the MEVVA ion source.

(v) Dr. Xavier Godechot, University of Paris-Sud, and SODERN, France, for a 12-month stay, to participate in the whole range of MEVVA r&d activities.

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28. We are indebted to Dr. Bruce Sartwell and co-workers at NRL for this collaboration.

APPENDIX

OTHER ACTIVITIES

The International Conference on Ion Sources was held at Berkeley, July 10-14, 1989. This meeting was organized and chaired by me. The meeting was highly successful. More than 150 papers were presented. There were 228 participants, and 23 different countries were represented. There was unanimous agreement to hold a second such conference, and this has been scheduled to be held in October, 1991, in the vicinity of Darmstadt, W. Germany.

Several guest scientists visited my laboratory for various lengths of time to participate in the ongoing research. They were from Australia, W. Germany, Japan, and France.

A paper was presented at the Workshop on Research and Technical Transfer of Ion Implantation Technology for Speciality Metals, held at Knoxville, TN, October 26-27, 1989, and organized and chaired by Dr. Bob Reeber of ARO. The paper, "High Current Metal Ion Source for Ion Implantation", reviewed the MEVVA technology developed at LBL and summarized the various ion implantation programs being carried out. The Workshop was very productive and led to a number of contacts and new programmatic directions, including collaborations with Corpus Christi (helicopter parts implantation), with NRL (metal fatigue improvement), and with Watertown MTL re a MEVVA implanter study.

My book, *The Physics and Technology of Ion Sources* (Wiley, NY, 1989) was published during the period of the contract.